

AN AUTOMATIC, ON LINE TELEMETRY PROCESSING SYSTEM

by

Richard G. Holmes

and

H. Robert Stagner

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

National Aeronautics and Space Administration
Coddard Space Flight Center
Greenbelt, Maryland

N66-18337

FACILITY FORM 602

(ACCESSION NUMBER)
21
(PAGES)
TMX 56539
(NASA CR OR TMX OR AD NUMBER)

(THRU)
1
(CODE)
08
(CATEGORY)

XERO
COPY

XERO
COPY

XERO
COPY

INTRODUCTION

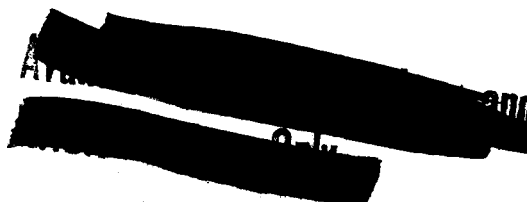
From August 28, 1964, until September 22, 1964, the NIMBUS Meteorological Satellite transmitted to earth a large amount of meteorological data, which it had acquired through television cameras and a High Resolution Infrared (HRIR) sensor. This data was used to produce photofacsimile film strips of the earth's cloud cover, particularly on the unlit side of the earth, thus providing immediate, visual, meteorological information. Because of the inherent limitation in resolution due to the photographic reproduction technique it was also required that the infrared data be subjected to a very detailed computer analysis.

This paper describes a new approach to the problem of preparing such analog telemetry data for computer analysis.

The NIMBUS HRIR Digitizing System, now operating at the Goddard Space Flight Center (GSFC) applies the concept of an automatic, computer-controlled production system to the field of telemetry processing. The system utilizes a medium-size digital computer (Figure 1), operating "on-line" in a "real-time" environment with the required signal processing and digitizing equipment (Figure 2). The purpose of the system is to convert an analog signal into digital samples and to perform preliminary on-line processing and quality control of this data prior to its entry into a large-scale digital computer where detailed experimenter analysis is performed.

BACKGROUND

The field of electronic processing of large masses of telemetry data is as new as the space age. From the early days of telemetry until quite recently the amount of data involved was small and simple processing techniques utilizing strip charts for example was sufficient. With the advent of high data rate satellites carrying several experiment packages and transmitting over a period of several months the need developed for faster, more efficient, and more accurate processing techniques. A large scale digital computer lends itself very well to these problems, requiring only the preparation of the analog data for entry into it. An early solution (and the one used currently in most automatic processing at GSFC) to the problem of preparing the data for a large scale computer used a two step process. In the first step the data and calibrating signals are digitized, time is decoded and digitized, and the digital values are placed on digital computer compatible buffer tape. In the second step the buffer tape provides the input to a medium scale digital computer which performs the preliminary processing functions of editing, quality control, time correction, formatting and data accounting. The output of this computer is a magnetic tape properly prepared for entry into a large scale digital computer, where detailed experimenter analysis is performed. In this experimenter analysis, which may consist of one or several passes through computers and plotting devices, experiment calibrations, equations, and correlations are applied and final listings and plots are produced.



Studies performed as part of the system design of the HRIR Digitizing System showed definite cost advantages of an on-line system as opposed to the two step approach. The saving is mainly the result of reducing the amount of required computer time and manpower requirements. Additional advantages are found in reducing the accounting functions, minimizing the amount of magnetic tape involved, and providing immediate feedback to the operator on the condition of the digitizing equipment and quality of the data.

To better understand the problems involved and the need for digitizing the data, a description of the spacecraft data source, transmission links, and final use of the data is given.

SPACECRAFT

The NIMBUS spacecraft was designed to orbit the earth in a nominally circular high noon polar orbit once every 106 minutes so that its orbital motion combined with the rotation of the earth would enable it to photograph all of the earth's surface once every 24 hours. During the daylight portions of the orbit, television cameras would create optical earth images while during the nighttime portions of the orbit infrared scanning devices would scan the earth to produce nighttime infrared images. The HRIR experiment is mounted on the bottom of the circular body of the spacecraft (Figure 3) and consists essentially of a lead selenide (Pb Se) photoconductive cell which operated in the 3.5-4.1 micron window region. The radiation is focused onto the cell by a rotating mirror which produces a scan of the earth at a right angle to the direction of motion of the spacecraft once each revolution (see Figure 4). This scanning combined with the

orbital motion of the spacecraft produces a series of rasters which are combined to form a facsimile picture of the total radiation in the spectral band received from the earth (see Figure 5). To provide the necessary reference for aligning the scans a permanent magnet on the scanning mirror axis triggers a multivibrator to generate a seven pulse sequence once each scan. A calibration check is provided when the mirror is viewing the spacecraft housing, which is at a known temperature. The HRIR signal then consists of an earth view, outer space view, housing view and synchronization pulses as shown in Figure 6. This signal modulates a voltage controlled oscillator to produce a frequency modulated signal which is recorded on one of four tracks of an onboard tape recorder for playback to one of two ground tracking stations once each orbit. An amplitude modulated time code (similar to the NASA 36 bit BCD Time Code) shown in Figure 7, but modulated on 10 kc instead of 1 kc, is recorded on a second track to permit later correlation of the data with earth coordinates. When the spacecraft recorder reaches the end of the tape it reverses and the two signals are recorded on the remaining two tracks. At playback data from all four tracks are transmitted at once, causing data and time on one pair of tracks to be transmitted in a forward direction (as recorded) and the other pair to be transmitted in a reverse direction. These signals are recorded at the ground station on four tracks of an analog tape recorder with ground time being added at this time on a fifth track.

The radiometer can resolve temperature to $\pm 2K$, the facsimile photos can be resolved to, perhaps, 10 gray levels or $\pm 10^3K$. To provide all of the information available from the signal and to allow detailed analysis in a digital computer, digitizing is required.

Not only does digitizing provide greater resolution, as can be noted by comparing the facsimile film strip in Figure 8 with the same data (Figures 9, 10, 11 and 12) after having been digitized and then analyzed and plotted by the experimenter, but digitizing also enables more complex computer analysis such as computing cloud elevations from the temperature data.

GENERAL DESCRIPTION

The HRIR Digitizing System (Figures 13) consists of a medium scale digital computer operating "on-line" with the HRIR digitizing equipment. The two portions of the system are divided by functional considerations. The HRIR equipment contains those functions, such as demodulation, which must be done external to the computer, leaving to the computer those functions of a computational or processing nature. Some functions which could be performed in either the computer or HRIR equipment, such as bit pattern recognition, are done very efficiently in the HRIR equipment and thereby save computer time.

After the HRIR equipment is connected to the computer, the computer program automatically sets up the system for the run using information obtained through the card reader and typewriter.

In this setup process the program engages in a conversation with the operator in which the program requests of the operator any needed parameters, warns him of any anomalies in the system readiness, and gives directions for corrective action. A typical typewriter log of this conversation is given in Figure 14.

Following verification of system readiness analog data and time code signals are read into the HRIR equipment from an analog tape, which contains the satellite telemetry signals and the ground time signal as recorded during a pass of the spacecraft over a ground station. In the HRIR equipment the analog data are demodulated, digitized and read into the computer in a stream of data words each of which consists of a sample of 8 bits plus 4 "flag" bits. Simultaneously with the digitizing of data the ground and vehicle time signals are processed through time decoding circuits which obtain time word synchronization and separate the 4 bits of each BCD time character from the encoded bit stream. These two sets of BCD time characters are then multiplexed and enter the computer through a second channel a character at a time. Data quality and status flag symbols are added to both the data words and the time words by the HRIR equipment. The equipment also provides computer "interrupts" upon detection of certain time and data synchronization conditions.

The computer temporarily stores the time and data, determines the correct vehicle time word and ground time word from the multiplexed vehicle and ground time characters, correlates the vehicle time with the data, checks the quality of the time and data using the flags set by the HRIR equipment, and produces properly formatted digital output tapes.

The computer also provides a concurrent printout of system performance and data quality. Thus all processing functions

needed to transform the frequency-modulated analog telemetry and amplitude-modulated time signals into a digital format suitable for further analysis on a large scale digital computer are accomplished in one pass through the system.

XERO
COPY

XERO
COPY

XERO
COPY

XERO
COPY

XERO
COPY

XERO
COPY

HRIR EQUIPMENT FUNCTIONS

The HRIR equipment (see Figure 13) consists of an analog tape drive, A/D converter, FM discriminator with tape speed compensation, time decoder, associated logic circuits, and a strip chart recorder. Additional circuits were included to allow the equipment to appear exactly as a standard piece of computer peripheral hardware. This allows selecting initial conditions under program control, sensing of conditions within the equipment by the program, and the use of the "program interrupt" feature for certain hardware functions. In addition operator functions on the hardware are minimized by placing them under computer control, which allows a check to be made that the settings desired were actually made. Adaptive control is possible in the system, however no attempt has been made to use it.

The demodulation of both the amplitude modulated time codes and the frequency modulated data signal of necessity is done in the external equipment as is the analog-to-digital conversion of the data. The data discriminator and A/D converter are standard commercial units. Detection of the amplitude modulated time codes is accomplished using energy detecting techniques followed by additional logic circuits to improve upon the reliability of detection.

The time code carriers are used throughout the equipment as a source of timing signals. To provide reliable, noise-free signals for this purpose circuits were designed whose outputs are frequency- and phase-locked to the input. If their input should disappear, the output of

these circuits continues for some time at the last frequency. These circuits have been named "flywheels" because of their continuing output.

Communication between the computer and the HRIR equipment is through 4 of the 6 available I/O channels. Channel 1, operating in the double word mode transfers 48 bits of data into the computer. The external equipment accumulates data words of 12 bits each to make up the 48 bits for transfer. Channel 2 is a 48 bit output channel and is used for the transmission of "select" and "sense" code from the computer. "Select" codes set up operating modes, and "sense" codes test critical conditions, within the external equipment. Channel 5 operates in the half word mode and transfers a 12 bit word into the computer. This channel carries ground and vehicle time characters which have been multiplexed in the hardware. Channel 6 carries a single select code to the hardware.

Those processing functions which could be performed in either hardware or software and are done in hardware consist of time code synchronization pattern recognition for both ground and vehicle time, determining forward or reverse direction of the vehicle time code, and data synchronization recognition. Time code synchronization recognition is accomplished by looking for a unique pattern of 1's and 0's in the incoming time code. This pattern is found in the tenth time character and is 1110011111. Circuits are included which count the number of bits from one synchronization pattern to the next as a means of determining when the next synchronization pattern is expected. A computer interrupt is generated

whenever the synchronization pattern is detected when expected. Forward or reverse time code is detected in a very similar manner. The time code synchronization pattern is examined and if found to be as shown above the time is forward, if the pattern is the reverse of the above, 1111100111, time is running in reverse. This provides a means of automatically switching tracks of the tape deck to acquire the desired input. Data sync detection requires threshold and pulse width detection, and counting of sync pulses. As these are essentially pattern recognition functions, they are more economically performed in the HRIR equipment than in the computer.

COMPUTER PROGRAM FUNCTIONS

The computer used, a CDC 924, is a binary 24-bit per word, parallel arithmetic machine, providing 3 buffered input and 3 buffered output channels, 5.3 microsecond effective memory cycle time, one programmable internal interrupt and two external interrupts, and the ability to input-output in either a half word, full word, or double word mode.

The program itself has been written in two independent sections referred to as the Controller and Processor. The Processor performs those functions of a computational or processing nature and the Controller performs all other functions. Dividing the program into 2 sections facilitated the writing of it as well as its checkout. Two persons were able to proceed independently in the writing and checkout of the separate sections with a minimum of communication.

The Controller section provides overall system control and function synchronization, and provides for all input-output functions and interrupt processing. In the initial system setup phase the Controller automatically selects and verifies the desired system settings, which had been specified by a previously prepared set of IBM cards, indicates to the operator any anomalies noted in either the cards or system readiness, and suggests corrective action if possible. The external equipment settings which the controller selects are:

1. sampling rate - 2, 4, 8, or 18 K samples per sec
2. data source - analog tape, system simulator or digital tape
3. data direction - forward or reverse
4. flywheel bandwidth - 200 cps, 500 cps or 1 Kc

In addition the Controller modifies itself to run in either a production or a checkout mode.

To provide for the input to data from the external equipment 5 fixed length data buffer areas have been set aside within the magnetic core memory. (see Figure 15) The buffer area is composed of sections, each of which accumulates similar functions (i.e., ground time characters, vehicle time characters, data samples etc.) which occur during the input time of that particular buffer. The filling of a buffer is referred to as a buffer cycle. Program operations are routed to these different buffer areas, in place of moving the buffers to new memory locations, to eliminate a nonproductive use of computer time. At any time during the operation, time and data words are being placed in one buffer, the processing program is operating on a second, the third and fourth

buffer areas are being held and the fifth is being put out on digital tape. While a buffer area is filled the controller monitors the data input channel, the time input channel, and both external interrupts. The monitoring is accomplished through the use of "program requested interrupts", a feature of the computer which requires no computer time for the monitoring function.

When a buffer area is full the Controller reassigns the buffer areas, performs some system status checks, and reactivates the input channels. The status checks performed include determining if the operator desires to end the run, checking that the last output record was correctly written on tape, confirming that the HRIR signal was present at the external equipment during the cycle and that no time or data words were lost at the external equipment-computer interface, and verifying that the computer program has completed everything required of it. The system status and diagnostic information obtained from the checks are made available to the operator by means of the printout produced concurrently with the processing. This information for the operator, which provides a record-by-record summary of the system performance, is compiled and periodically (about every 8 seconds) is printed out. The information enables the operator to take corrective action, if necessary. After the processing operation the printout serves later users as a summary of data quality.

Two major operational modes were incorporated into the Controller, the production mode just described and the checkout, or diagnostic, mode. In the checkout mode the controller is modified to delete or

add routines, skip over inoperable instructions and change the input source, as specified by input IBM cards. The output data tape in the checkout mode contains the data that is most useful in trouble shooting and "debugging." It contains the input BCD time characters, the results of interrupt processing, and all "flag bits" set by the processor. The checkout mode of operation with a digital tape providing a simulated input proved invaluable in locating program flaws prior to integrating with the external equipment. Also, the problems associated with interfacing the programs with the external equipment were minimized by operating in the checkout mode. Other diagnostics that are available provide a log of where the program was when each data channel interrupt occurred, indicate whether the program is completing all functions required of it, and show how much extra computer time is available.

Once each buffer cycle control of the program is transferred to the processor section where the computations on time and data are performed. There is no direct communication between the Processor and Controller; rather, all information is found within the buffer area to be processed, or within the Processor itself. The Processor stores both needed parameters and carry-over information from the last buffer processed. The functions performed by the Processor are to demultiplex the ground time and vehicle time characters, check for invalid characters, convert the BCD time words to a binary day of the year and seconds of the day, search for new time sequences, correlate vehicle time with data, and examine the data synchronization information. The Processor

accumulates information about the time words so that in the event of invalid time characters, or if the time word is not 1 sec greater than the last, it may insert its own estimate of the proper time word. The inserted time word may be in error if a time skip, or new sequence, is beginning. After a few time words if a new time sequence is evident, the processor is able to return to the two previous buffers processed, which are being held, and modify the time words it had inserted to correspond to the new sequence. Using the time synchronization interrupt information with predicted interrupt location information that it compiles the processor is able to provide information that correlates time with data and indicates the reliability of the correlation. By accumulating information on data synchronization interrupts and examining the interrupt locations the processor is able to indicate the reliability of the detection and in some cases is able to improve on it.

SYSTEM PERFORMANCE AND CONCLUSIONS

Production runs indicate that the system is capable of operating as designed at all digitizing rates. During a typical run twelve analog tape passes were processed in a total time of three hours. This processing time of 15 minutes per analog tape pass was governed solely by the time it took to mount the analog tape, run it through to the end of the data, and unload the tape. No manual searching for the desired data was needed as the external equipment automatically selects the needed tape track for forward or reverse data, switching as needed during the pass.

Because of the automatic set up of the system and the built in confirmation of the systems readiness there is little chance of operator error. The computer program, including tables and temporary storage, occupies 10,000 words. An additional 10,360 are used for the five buffers. In a typical program cycle a total of about 3,000 instructions are executed or less than one instruction per data sample. With a program cycle taking 0.225 seconds at the 16,000 samples per record digitizing rate this leaves 0.195 seconds or 87 percent of the time during which the program is idle, assuming a conservative 10 microseconds per instruction.

In later systems part of this time could be utilized in more detailed analysis of the data, and in employment of the inherent capability of the system for dynamic adjustment or feedback techniques to improve the quality of data coming from the external equipment.

The system philosophy of the Nimbus HRIR line thus provides considerable advantages over previous, multipass systems in that intermediate digital tapes are eliminated, throughput time is cut drastically, accounting requirements are minimized, and immediate quality control feedback to the system digitizing operator are provided. As a result savings are realized in operating time, effort, and cost.

References

Nordberg, W., NIMBUS I Meteorological Satellite
GSFC document X651-65-196

Stampfl, R. A., The NIMBUS Spacecraft and
its Communication System as of Sept. 1961.
NASA Technical Note D-1422

NIMBUS I High Resolution Radiation Data
Catalog and Users Manual Vol I